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USE OF ARNO CONVERTER AND MOTOR-GENERATOR SET TO CONVERT A SINGLE-PHASE AC SUPPLY TO A THREE-PHASE AC FOR CONTROLLING THE SPEED OF A THREE-PHASE INDUCTION MOTOR BY USING A THREE-PHASE TO THREE-PHASE CYCLOCONVERTER

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ABSTRACT

This method is used to control the speed of a three-phase induction motor by using a three-phase to three-phase cycloconverter from a single-phase supply and to compare the use of ARNO converter and motor-generator set to convert a single-phase supply to a three-phase supply. ARNO converter is a rotating device which convert single-phase AC to three-phase AC. The three-phase supply needed for the three-phase induction motors which used in blowers, exhausters an oil pumps. A motor-generator set is a device for converting electrical power to another form. They are used to convert frequency, voltage or phase of power. Thus, both ARNO converter and motor-generator set have been used here one at a time to convert a single-phase AC supply to three-phase AC. Both have their own advantages and disadvantages. After that, the three-phase supply has been given to three-phase to three-phase cycloconverter. Cycloconverters are used to convert a single-phase or three-phase AC to variable magnitude or variable frequency, single-phase or three-phase AC without a DC link. This cycloconverter is then connected to a three-phase induction motor to control their speed. The formula for the speed of an induction motor is Ns=120f/p. So, here the speed is dependent on frequency and no. of poles. It is directly proportional to the frequency and inversely proportional to the no. of poles. Since, cycloconverter is a frequency changing device. Thus, it plays a great role to control the speed of the induction motor by varying its frequency. Among all the methods, this method is economical, reliable and simple.

1. INTRODUCTION

ARNO converter is a rotary converter which has a combined set of winding and is used to convert the single phase AC supply to 3-phase AC which is fit for use by various machines. ARNO is basically a split-phase induction motor with an additional winding on the stator for the generating phase. In an induction motor, the rotating field of stator creates a corresponding field in the rotor squirrel cage too which causes the rotor to start rotating at a slip speed which is slightly less than synchronous speed. However, this rotating field of the rotor is additionally utilized in the ARNO to create power in the generating phase winding which gives the 3-phase output of the ARNO converter. In the stator winding of the ARNO, the motoring phases carry the load as well supply currents of the ARNO in opposite direction which causes a net reduction in the actual current carried by the winding in the stator but the generating phase carries only the load current which cause a voltage drop in the generating phase.

Like ARNO, motor-generator set can also be used to convert a single-phase AC supply to a three-phase AC. In the context of electric power generation and large fixed electrical power systems, a motor–generator consists of an electric motor mechanically coupled to an electric generator (or alternator). The motor runs on the electrical input current while the generator creates the electrical output current, with power flowing between the two machines as a mechanical torque; this provides electrical isolation and some buffering of the power between the two electrical systems. After that, the three-phase supply which is formed is applied to a three-phase to three-phase cycloconverter. The three-phase to three-phase cycloconverter circuit, using six three-phase half-wave thyristorised converters (two per each phase), is described. The operation of the cycloconverter circuit is briefly discussed. The mode of operation is the non-circulating current one. The analysis of the cycloconverter output waveform is presented. The procedure for obtaining the expression for the output voltage (rms) per phase for cycloconverter is described. This circuit is then used to control the speed of a three-phase induction motor, which is very necessary in industrial application.

2. OPERATING PRINCIPLE OF AN ARNO CONVERTER

The single –phase supply of 380 volts AC is fed 'direct' to the 'U' and 'V' phases of the ARNO converter. Since the ARNO converter is connected to a single phase supply, no starting torque is developed. For starting the ARNO, split phase starting method has been employed. The 'W' phase winding is connected to the supply phase 'U' through a starting resistor R-118 and starting contactor C-118 for a short duration to start the ARNO. Thus, unbalance three-phase voltage is impressed to each phase winding of ARNO converter and the starting torque is developed. The ARNO converter picks up speed within five seconds. After the ARNO has gained sufficient speed, the phase 'W' is opened from the starting circuit by starting contactor C-118.

The ARNO converts the single-phase input to three-phase output as 380 volt + or − 22.5%. Three-phase output of the ARNO converter is connected to the motors.
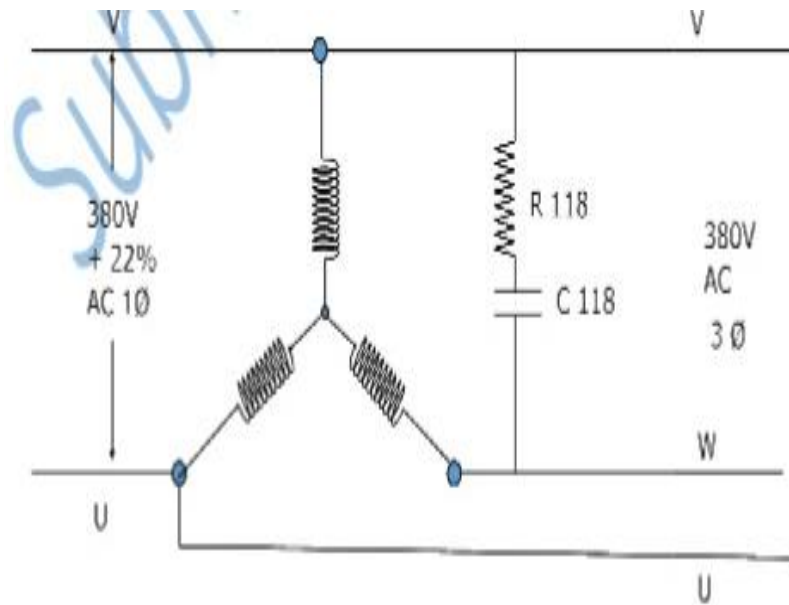
Fig : Circuit Diagram of Amo Converter

3. OPERATING PRINCIPLE OF A MOTOR-GENERATOR SET

A motor generator (M-G) set refers to a composite device consisting of a motor and a generator mechanically coupled through the common shaft. Practically a motor generator set is a system where a motor and a generator are connected or rather placed in a single circuit.
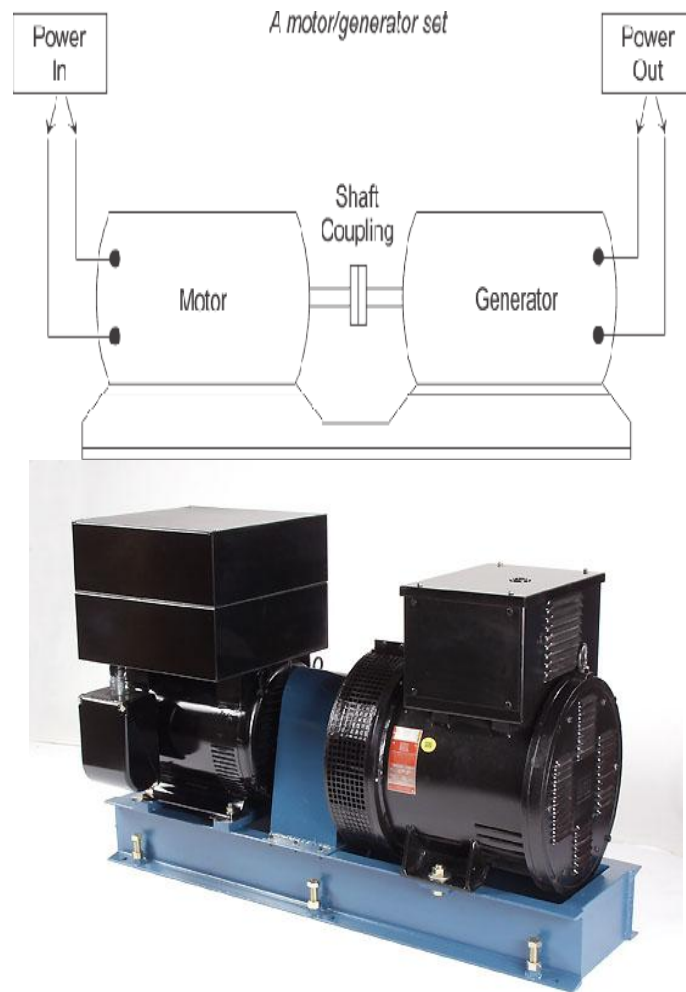
Figure Motor-generator set

From the above diagram we can see that in a typical motor generator set, the power is given externally to a motor and as a result the shaft of the motor rotates the rotor of the generator. That means, motor receives electrical energy input from the supply line. Its shaft rotates and since the generator shaft is mechanically coupled with it, the generator also receives its mechanical input through shaft. Thus generator also creates electrical output power or in other words generator converts the mechanical energy into electrical energy. Thus while the power at the input as well as output side is electrical in nature, the power flowing between the machines is in form of mechanical torque. This provides isolation of the electrical system as well as some buffering of power between the two electrical systems.

4. THREE-PHASE TO THREE-PHASE CYCLOCONVERTER

Two three-phase half-wave (three-pulse) converters connected back to back for each phase, with three thyristors for each bridge, are needed here. The total number of thyristors used is 18, thus reducing the cost of power components, and also of control circuits needed to generate the firing pulses for the thyristors. This may be compared to the case with 6 (six) three-phase full-wave (6-pulse) bridge converters, having six thyristors for each converter, with total devices used being 36. Though this will reduce the harmonic content in both output voltage and current waveforms, but is more costly. This may be used, where the total cost may be justified, along with the

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merit stated. The ripple frequency is 150 Hz, three times the input frequency of 50 Hz.
Here, the circulating current mode of operation is used, in which both (positive and
negative) converters in each phase, conduct at the same time. Inter-group reactor in
each phase is needed here. But, if non-circulating current mode of operation is used,
where only one converter (positive or negative) in each phase, conducts at a time, the
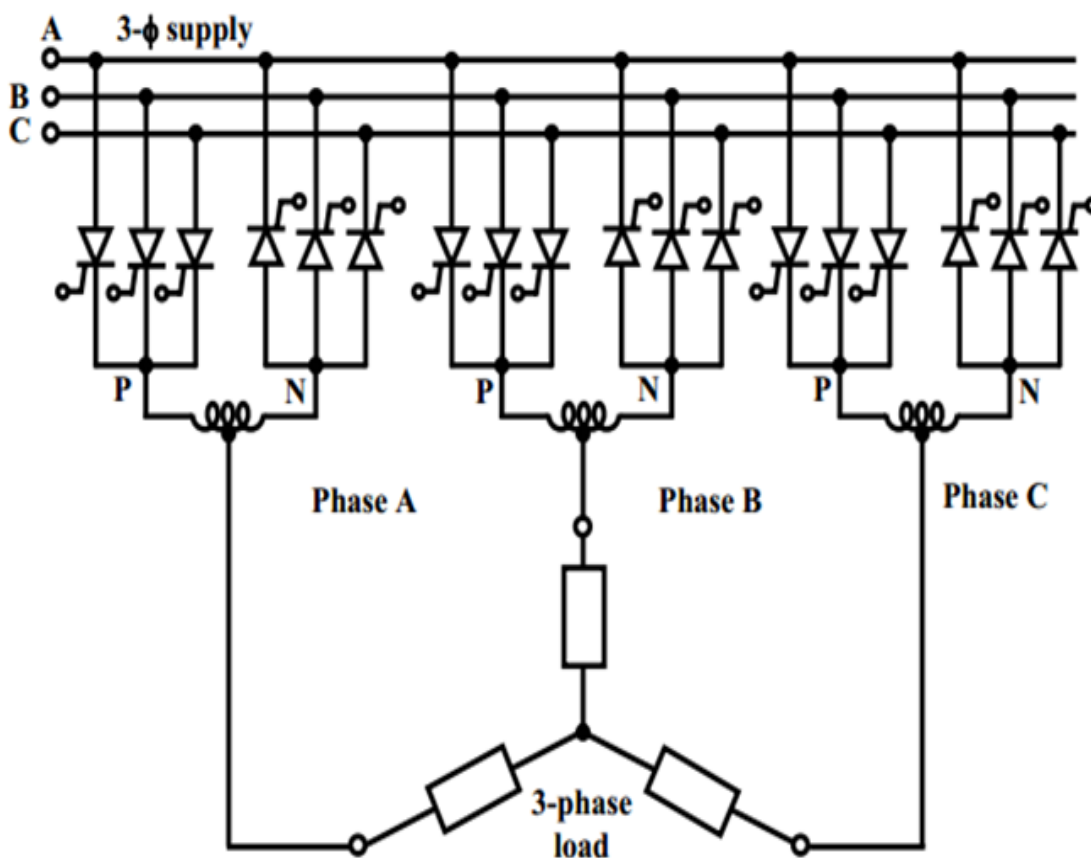reactors are not needed.

Figure Three-phase to three-phase cycloconverter

The firing sequence of the thyristors for the phase groups, B & C are same as that
for phase group A, but lag by the angle, 120° and 240°, respectively. Thus, a balanced
three-phase voltage is obtained at the output terminals, to be fed to the three-phase
load. The average value of the output voltage is changed by varying the firing angles
(α) of the thyristors, whereas its frequency is varied by changing the time interval
(T/3=1/ (3f)), after which the next (incoming) thyristor is triggered. With a balanced
load, the neutral connection is not necessary, and may be omitted, thereby suppressing
all triplen harmonics. Normally, the output frequency of the cycloconverter is lower
than the supply (input) frequency (step-down region), limited to about one-third of it.
This is necessary for obtaining reasonable power output, efficiency and harmonic
content. If the output frequency is to be increased, the harmonic distortion in the
output voltage increases, because its waveform is composed of fewer segments of the
supply voltage. Thus, the losses in cycloconverter and also in ac motor become
excessive. By using more complex converter circuits with higher pulse numbers, the
output voltage waveform is improved, with the maximum useful ratio of output to
input frequency is increased to about one-half.

5. ANALYSIS OF THE CYCLOCONVERTER OUTPUT WAVEFORM

An m-phase converter circuit is assumed in which each phase conducts for $((2\pi)/m)$ electrical radians in one cycle of supply (input) voltage. For example, in a three-phase, half-wave (three-pulse) converter (m = 3), each phase conducts for $((2\pi)/3) = 120°)$ radians in a cycle of (2π) radians. Similarly, in a three-phase, full-wave (six-pulse) converter (m = 6), the conduction period of the periodic waveform is $((2\pi)/6) = \pi/3 = 60°)$ radians in one cycle. The output voltage waveform for an m-phase converter with firing delay angle α. With the time origin, PP′ taken at the peak value of the supply voltage, the instantaneous phase voltage is given by e = E(m) cosωt = 2^(1/2) E(ph) cosωt where, E(ph) = Supply voltage per phase (rms).
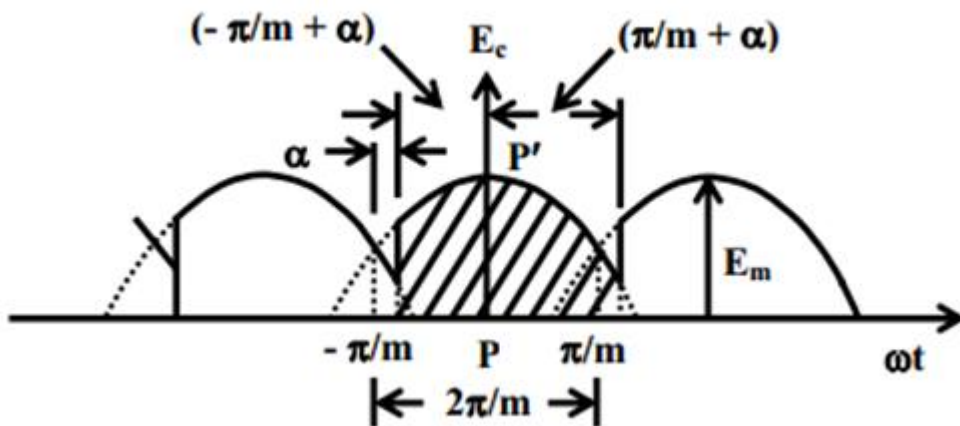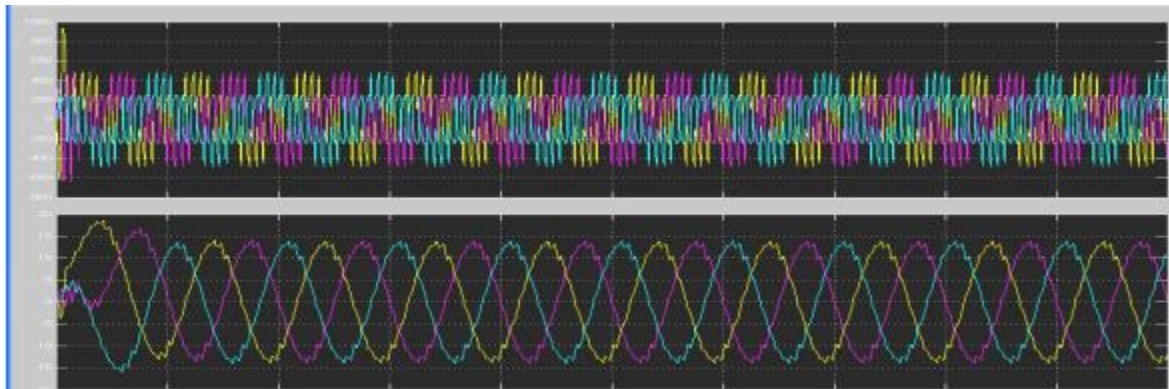

Figure Output voltage waveform for m-phase converter with firing angle α

Waveform of three-phase to three-phase cycloconverter

From here, it can be observed that the conduction period is from $(-\pi/m)$ to (π/m), if the firing delay angle is α=0°. For the firing delay angle α , the conduction period is from $(-(\pi/m)+\alpha)$ to $((\pi/m)+\alpha)$. From the above cases, the total conduction period is $(2\pi/m)$.

The average value of the output voltage is,

$$E_{dc} = \left(\frac{m}{2\cdot\pi}\right)\cdot\int_{(-(\pi/m)+\alpha)}^{((\pi/m)+\alpha)} \sqrt{2}\,E_{ph}\cos\omega t\; d(\omega t) = \sqrt{2}\,E_{ph}\cdot\left(\frac{m}{\pi}\right)\cdot\sin\left(\frac{\pi}{m}\right)\cdot\cos\alpha$$

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This expression is obtained for dc to ac converter in module 2, and also available in text book. When the firing delay angle is α=0°, E(dc) has the maximum value of

$$E_{d0} = \sqrt{2} \cdot E_{ph} \cdot \left(\frac{m}{\pi}\right) \cdot \sin\left(\frac{\pi}{m}\right)$$

If the delay angle in the cycloconverter is slowly varied as given earlier, the output phase voltage at any point of the low frequency cycle may be calculated as the average voltage for the appropriate delay angle. This ignores the rapid fluctuations superimposed on the average low frequency waveform. Assuming continuous conduction, the average voltage is = E(dc)= E(d0)cos α . If E(0) is the fundamental component of the output voltage (rms) per phase for the cycloconverter, then the peak output voltage for firing angle of 0° is

$$\sqrt{2} \cdot E_{0r} = E_{d0} = \sqrt{2} \cdot E_{ph} \cdot \left(\frac{m}{\pi}\right) \cdot \sin\left(\frac{\pi}{m}\right)$$

$$\text{or, } E_{0r} = E_{ph} \cdot \left(\frac{m}{\pi}\right) \cdot \sin\left(\frac{\pi}{m}\right)$$

However, the firing angle of the positive group, α(p) cannot be reduced to zero (0°), for this value corresponds to a firing angle of (α(n) = 180°) in the negative group. It may be noted that the firing delay angles of the two (positive and negative) converters are related by (α(n)+ α(p)= 180°). In practice, inverter firing cannot be delayed by 180°, because sufficient margin must be allowed for commutation overlap and thyristor turn-off time, as given in module 2. Consequently, the delay angle of the positive group cannot be reduced below a certain finite value, α (min). Therefore, the maximum output voltage per phase is, E(dc)(max) = E(d0)cosα(min) = r.E(d0), where min r = cos α(min) , and is called the 'voltage reduction factor'.

Thus, the expression for the fundamental component of the phase voltage (rms) delivered by the cycloconverter is,

$$E_{0r} = r \cdot \left[E_{ph} \cdot \left(\frac{m}{\pi}\right) \cdot \sin\left(\frac{\pi}{m}\right)\right]$$

6. THREE-PHASE INDUCTION MOTOR

Three-phase Induction motors convert three-phase AC electrical energy into mechanical energy. Of all electrical motors, three-phase induction motor is the most extensively used in industries and in other applications.

Operating principle

The stator of the motor consists of overlapping winding offset by an electrical angle of 120°. When the primary winding or the stator is connected to a 3 phase AC source, it establishes a rotating magnetic field which rotates at the synchronous speed.

According to Faraday's law an emf induced in any circuit is due to the rate of change of magnetic flux linkage through the circuit. As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, an emf is induced in the rotor copper bar and due to this emf a current flows through the rotor conductor. Here the relative velocity between the rotating flux and static rotor conductor is the cause of

current generation; hence as per Lenz's law the rotor will rotate in the same direction to reduce the cause i.e. the relative velocity.

Control and operation of two three-phase induction motors in cascade

In this method, two motors of same voltage ratings, motor A and motor B are used and are mechanically coupled. Motor A should be slip ring motor with 1:1 stator to rotor turns ratio and motor B may be of either cage or slip-ring type. The two motor should be wound for different poles, P(A) and P(B). Cumulative cascade connection is shown in below figure.
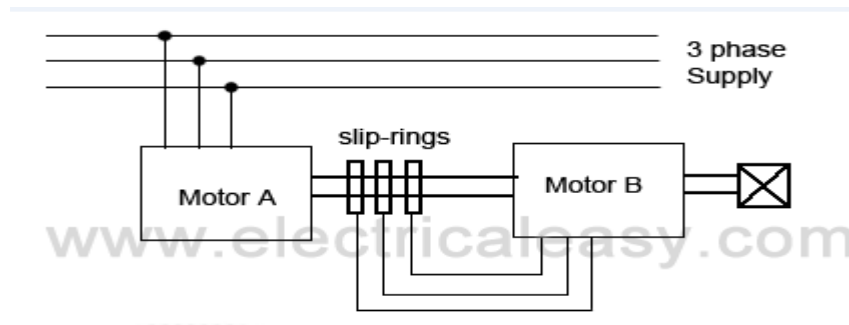
Here, the three phase supply is given to motor A and the stator terminals of motor B are connected to rotor terminals of motor A, in a phase sequence which will cause the rotating magnetic field set up in motor B to be in same direction as that of motor A. This cumulative cascade operation will give an effective synchronous speed, N(sc)= 120 f(s) /(P(A) + P(B)).

Here, we can see that the synchronous speed is directly proportional to the supply frequency. The variation of synchronous speed N(s) will vary the rotor speed N(r). The frequency of the normal supply is a constant, 50 or 60 Hz. Hence to employ this method, a separate variable frequency source is required. Because of this, a three-phase to three-phase cycloconverter is used, since it is a frequency changing device, which we have already discussed.

Application of cycloconverter in induction motor

Here, a three-phase induction motor has been connected as a load at the output terminals of the cycloconverter.
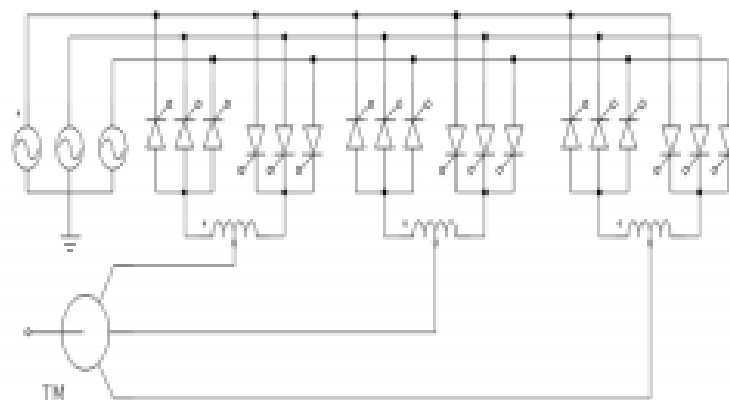

Figure phase to 3-phase cycloconverter with induction motor

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A control scheme is designed and simulated to control the operation of cycloconverter that Generates different frequencies in each specified Interval to drive three phase induction motor of variable frequency at variable supply voltage that generates the supply torque characteristics matching of demand torque characteristics of specific machine.
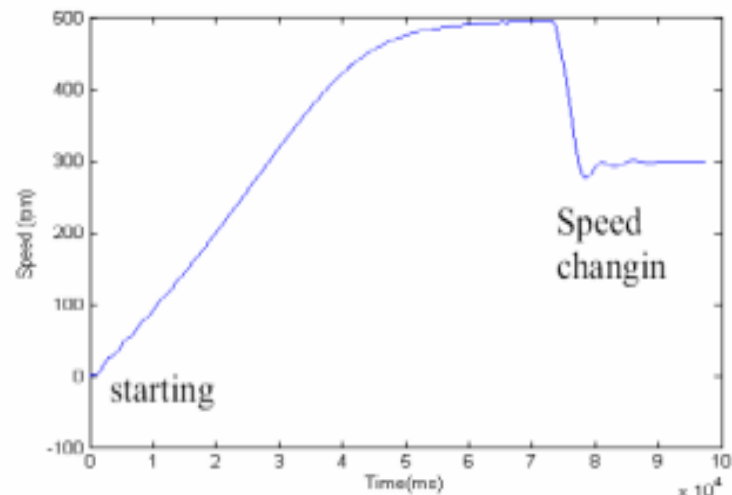

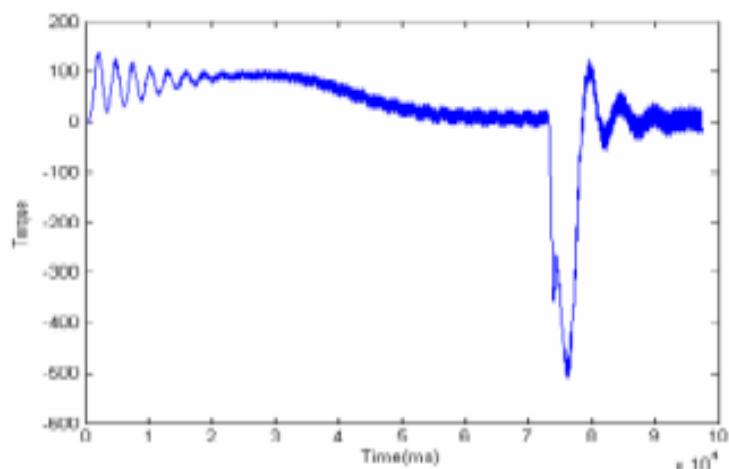**Figure** Motor speed due to starting and then changing the output frequency

Figure Motor torque during changing the output frequency

7. CONCLUSION

From this analysis, it is observed that the speed of a three-phase induction motor can be controlled by a three-phase to three-phase cycloconverter very efficiently from a single-phase AC supply, where the single-phase AC supply is converted to a three-phase AC by using an ARNO converter or a motor generator set. I also have done some analysis on to control the speed of two three-phase induction motors in cascade.

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